3. SEISMICITY OF SOUTHERN CALIFORNIA*

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Evidence for regional seismicity is of four kinds: (1) geological field observation of fault phenomena, (2) historical documents, (3) instrumental recording, and (4) field investigation immediately after earthquakes.

Historical and instrumental data cover a very small part of geological time, and thus constitute only a snapshot of the record, so to speak. They may furnish positive evidence of seismicity, but failure of earthquakes to occur on a given fault during a period of less than two centuries is no proof of quiescence. On the other hand, identifying faults as active on the basis of field evidence alone implies an assumption that there have been no significant permanent changes in seismicity in a few tens of thousands of years. This assumption is reasonable, but it does not necessarily apply without exception.

Faults are commonly identified as active on the basis of such field evidence as small scarps, especially if these cut young alluvial fans; slickensides in modern deposits; offsets in minor drainage channels; and sag ponds. There are differences, however, in the apparent age of these features. Many small features along the San Andreas fault are very fresh in appearance, and are known or believed to have originated during the earthquakes of 1857 and 1906. The rift topography along the Garlock fault includes many sag ponds, low scarps, and other geologically young features, but relatively few of these seem to be truly fresh. This suggests that no major earthquake has broken the surface along the Garlock fault within the last few centuries.

Known occurrences of fault-trace phenomena associated with recorded earthquakes in southern California are: (1) *January 9, 1857*. San Andreas fault, from Carrizo Plain to San Bernardino, and possibly farther in both directions; (2) *March 26, 1872*. Owens Valley; faulting, chiefly vertical with some strike-slip movement, along the line of the east front of the Alabama Hills (not along the major Sierra Nevada scarp several miles west); (3) *March 10, 1922*. San Andreas fault in the region of Cholame; large cracks, possibly not primary fault-trace effects; (4) *May 18, 1940*. Imperial Valley; fault trace at least 40 miles long, extending from the vicinity of Imperial and Brawley southeastward into Mexico; right-hand strike-slip movement, reaching a maximum displacement of 19 feet near the international boundary; scarps as much as 4 feet high; (5) *April 10, 1947*. Southeast of Manix, Mojave Desert; left-hand strike-slip movement of only a few inches along the line of the Manix fault; instrumental locations of epicenters of aftershocks aligned nearly at right angles to this fault, suggesting that the observed displacement is a secondary result of a larger displacement on a fault with different strike in the basement rocks; (6) *July 21, 1952*. Arvin-Tehachapi earthquake, Kern County; probably thrust faulting, with surface expression obscured and complicated by large-scale slumping and sliding; White Wolf fault.

The historical record begins with a strong earthquake felt by the Portola expedition on July 28, 1769, when the explorers were in camp along the Santa Ana River near the present townsite of Olive. Subsequent information for all of California is extremely scanty until 1850, and in southern California the record is imperfect for an even longer period of time. Especially in the desert areas, even a major earthquake could have escaped notice until about 1887, when the seismological station at Lick Observatory was established. In this same year the first catalogue of California earthquakes was published.

The greater earthquakes known to have occurred in the region of California and Nevada are: (1) *January 9, 1857*, San Andreas fault (see above); (2) *March 26, 1872*, Owens Valley (see above); (3) *April 18, 1906*, San Andreas fault: epicenter north of San Francisco; instrumental magnitude $8\frac{1}{4}$; (4) *October 1, 1915*, Pleasant Valley, south of Winnemucca, Nevada; instrumental magnitude $7\frac{3}{4}$; (5) *July 21, 1952*, Kern County; instrumental magnitude between $7\frac{1}{2}$ and $7\frac{3}{4}$ (investigation in progress).

Several less well known shocks, as those in 1812, 1836, 1838, 1852, and 1868, may have been comparable with these.

California forms a small part of the circum-Pacific belt of seismic activity (figs. 1, 2), which accounts for roughly 80 percent of the seismicity of the earth. Of this, southern California contributes between $\frac{1}{2}$ and 1 percent. Most of the circum-Pacific belt is composed of arcuate structures that are associated with deep as well as shallow earthquakes, very active volcanism, folding, and thrust faulting. California is the largest of several sectors in which the structures are not evidently arcuate, where only shallow earthquakes occur, and where the tectonics are primarily those of block faulting, including long, narrow rift zones associated chiefly with strike-slip faults.

In evaluating both historical and instrumental data, due attention should be paid to magnitude of the earthquakes. Frequently a comparatively moderate earthquake, such as the Long Beach earthquake of 1933, chances to originate in a thickly populated area and hence

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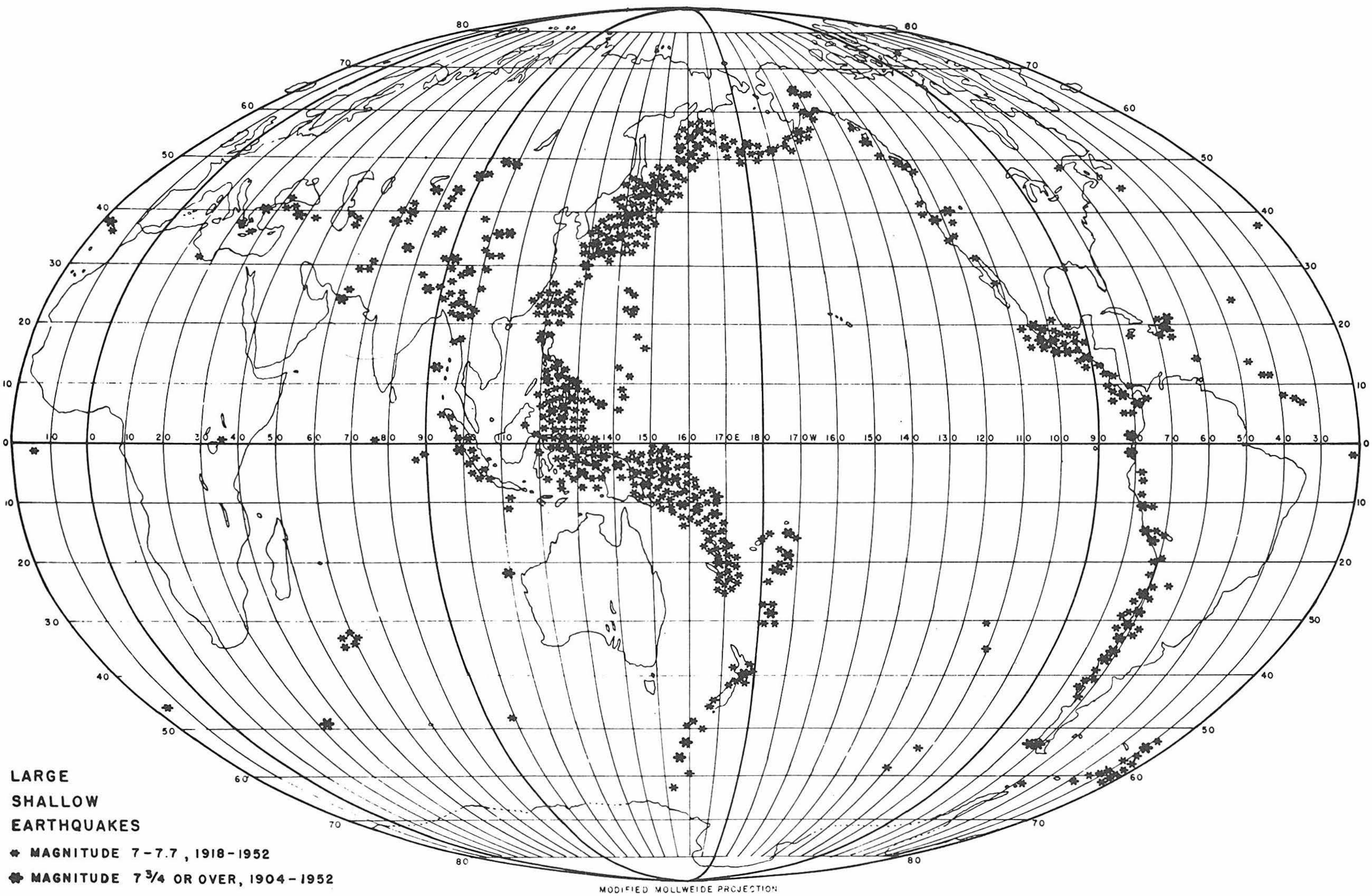

FIGURE 1. Large shallow earthquakes of the world, 1904-52.

Epicenter location, origin time, and magnitude of some of the shocks shown in figure 2.

Date	Time	Latitude	Longitude	Magnitude
1934, June 8	04:47:45	36 N	120½ W	6.0
1952, Nov. 22	07:46:38	35.8 N	121.2 W	6±
1922, March 10	11:21:20	35¾ N	120¼ W	6½
1946, March 15	13:49:36	35.7 N	118.1 W	6¼
1952, July 21	11:52:14	35.0 N	119.0 W	7.7
1947, April 10	15:58:06	35.0 N	116.6 W	6.4
1916, Oct. 23	02:44	34.9 N	118.9 W	5½±
1927, Nov. 4	13:50:43	34½ N	121½ W	7.3
1946, July 18	14:27:58	34.5 N	116.0 W	5¾
1941, July 1	07:50:55	34.4 N	119.6 W	5.9
1925, June 29	14:42:16	34.3 N	119.8 W	6¼
1930, Jan. 16	00:24:34	34.2 N	116.9 W	5¼
1935, Oct. 24	14:48:08	34.1 N	116.8 W	5¼
1940, May 18	05:03:59	34.1 N	116.3 W	5.4
1923, July 23	07:30:26	34 N	117¼ W	6¼
1947, July 24	22:10:47	34.0 N	116.5 W	5.5
1949, May 2	11:25:47	34.0 N	115.7 W	5.9
1930, August 31	00:40:36	33.9 N	118.6 W	5¼
1948, Dec. 4	23:43:17	33.9 N	116.4 W	6.5±
1941, Nov. 14	08:41:36	33.8 N	118.2 W	5.4
1933, Oct. 2	09:10:18	33.8 N	118.1 W	5.4
1918, April 21	22:32:25	33¾ N	117 W	6.8
1933, March 11	01:54:08	33.6 N	118.0 W	6¼
1937, March 25	16:49:03	33.5 N	116.5 W	6.0
1942, Oct. 22	01:50:38	33.3 N	115.7 W	5¾
1950, July 28	17:50:48	33.1 N	115.6 W	5.4
1950, July 29	14:36:32	33.1 N	115.6 W	5.4
1942, Oct. 21	16:22:14	33.0 N	116.0 W	6½
1951, Dec. 26	00:46:54	32.8 N	118.3 W	5.9
1940, May 19	04:36:41	32.7 N	115.5 W	6.7
1948, Feb. 24	08:15:10	32.5 N	118.5 W	5.3
1927, Jan. 1	08:16:45	32½ N	115½ W	5¾
1927, Jan. 1	09:13:30	32½ N	115½ W	5½
1935, Feb. 24	01:45:10	32½ N	115 W	5¼

does much more damage and attracts more general attention than major earthquakes, like those in Nevada in 1915 and 1932, which center in remote and sparsely populated areas. The instrumental magnitude scale, set up in 1932, defines the magnitude of a given earthquake as the logarithm of the trace amplitude, in units of 0.001 mm, as measured on the seismogram written by a specified standard instrument at a distance of 100 kilometers from the epicenter. For other distances, or for instruments of other types, reduction to the standard is accomplished by means of appropriate tables and computations. With due allowance for known local effects at the individual stations, magnitudes determined for the same earthquake at different stations are in good agreement, so that magnitudes commonly are assigned to the nearest tenth or quarter of a unit. The smallest instrumentally observed earthquakes are near the zero of the scale and the largest known are of magnitude 8.6. These numbers are not those of the commonly used local intensity scales, which rate the field effects (damage to structures, effects on terrain, etc.) in terms of an arbitrary scale ranging from I to XII. High intensity may result because an earthquake of moderate magnitude originates nearby or because an earthquake of large magnitude originates at a distance.

Some results of experience with the magnitude scale can be tabulated as follows:

Magnitude	Effects
1	Only observed instrumentally.
2	Can be barely felt (intensity II) near epicenter.
4½	Felt to distances of some 20 miles from the epicenter; may cause slight damage (intensity VII) in a small area.
6 +	Moderately destructive (example: Long Beach, 1933; Santa Barbara, 1925).
7 +	Major earthquake.
7¾ +	Great earthquake (1872, 1906).

Because of the late development of instrumental seismology, great earthquakes of magnitude 8 and over can be catalogued completely only for the period beginning in 1904 (fig. 1). Such earthquakes are related to the major active structures. Minor earthquakes, on the other hand, are more commonly related to minor faults and structures, and the epicenters of the small, instrumentally recorded shocks are peppered over the region.

Since 1932, epicenters for sufficiently well recorded shocks have been assigned from the data of the seismological network in southern California. This record includes most earthquakes of magnitude 3 and over, but with notable imperfections in the data for some shocks, particularly those about the margin of the area. A map showing such small shocks for the whole region is nearly certain to give a false impression; for example, these results have sometimes been misinterpreted as indicating relatively low seismicity in the offshore and island area to the southwest, an area that is comparatively remote from most of the established stations, and that is in a bad position for accurate locations. Figure 3 shows located shocks of magnitude 4½ and over, for the period 1934-51.

Figure 2, showing California and other western states, includes no shocks of magnitude under 5¼; those shown are consequently large enough to be recorded at distant stations. It is clear that a continuous belt of seismicity, continuous but irregular in detail, extends from the region of the north coast, the most active part of the entire region, southeastward and through the Gulf of California. The chief seismic zone widens south of the Transverse Ranges, owing to the branching of the San Andreas fault, and to the occurrence of other parallel active faults.

The earthquakes of the Great Basin and the Rocky Mountain regions, though occasionally large, are comparatively sporadic in occurrence and in geographical distribution.

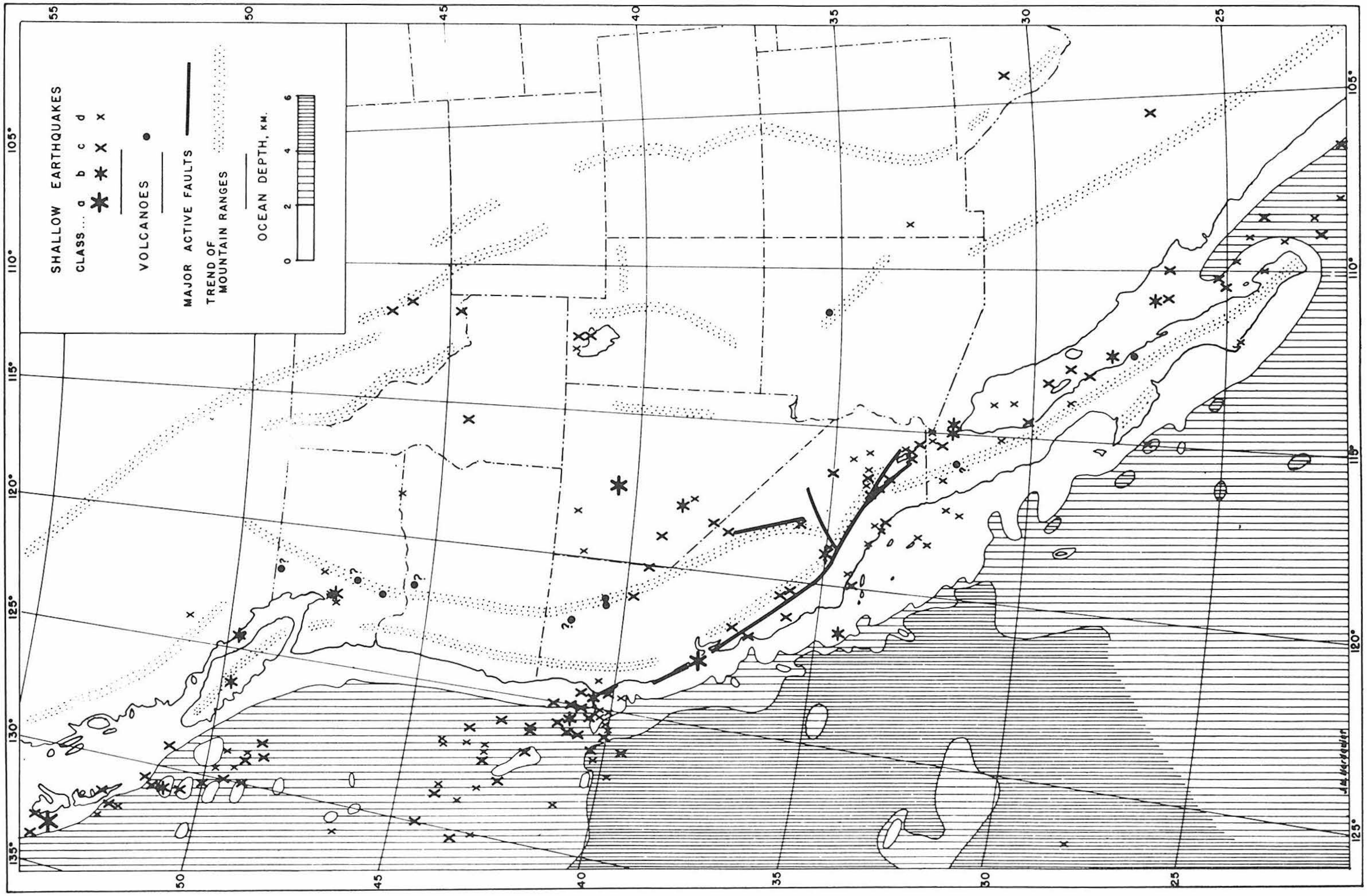

FIGURE 2. Seismicity of the Cordilleran United States and adjacent areas.

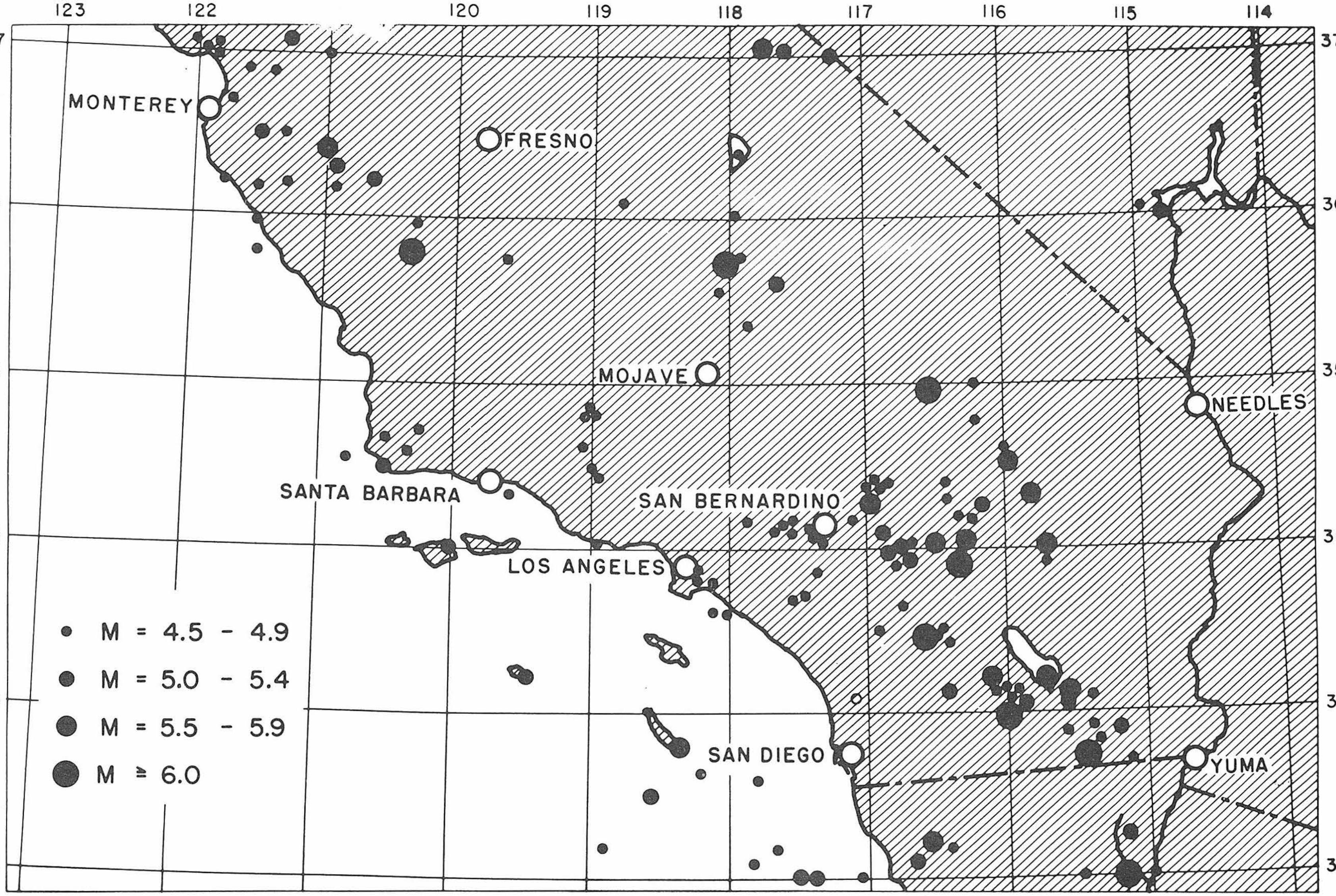

Figure 3. Earthquakes of magnitude 4.5 and over, southern California, 1934-51.

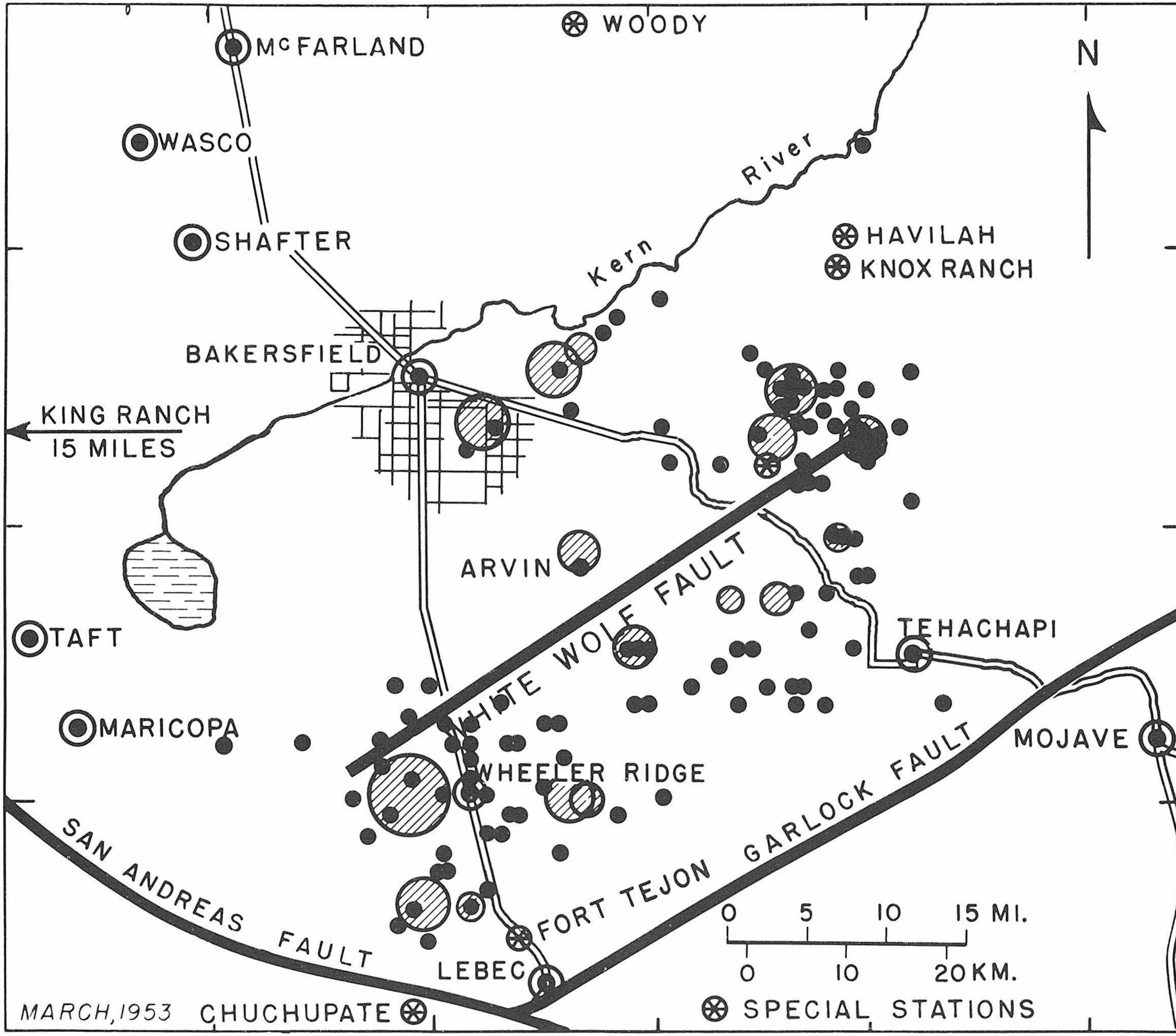

FIGURE 4. Kern County earthquake series, 1952. (See text for explanation of symbols.)

The accompanying table gives epicenter and origin time for those shocks shown in figure 2 between latitudes 32°30′N and 36°00′N.

For shocks such as those of 1906, 1940, and 1952, where there is notable linear extent of faulting, the instrumental epicenter is above the point of initial rupture, because this is the point of origin of the first seismic waves to be recorded at a given station. Not uncommonly, as in 1933 and 1952, the epicenter lies at one end of the active fault segment, and consequently is eccentric with respect to the heavily shaken area, and to the geographical distribution of aftershocks (fig. 4).

The location of almost every epicenter shown in figures 3 and 4 may be in error by 5 miles or even more. Great care should be exercised in using seismological data to discriminate between activity of closely spaced faults. A comparatively small difference in dip will have considerable effect on the relation of epicenter to surface trace, as the average depth of the hypocenter (the actual point of initial rupture, directly beneath the point mapped as epicenter), is about 10 miles.

In routine epicenter-location work at Pasadena, which involves determinations for about 250 local earthquakes each year, it has been customary to assign a fixed depth of origin of about 10 miles for southern California shocks, unless the available data clearly conflict with that assumption. This sometimes has been taken to mean that all southern California earthquakes originate at nearly the same depth. This is certainly not so; some probably originate at points as deep as 15 miles, and others at points within 5 miles of the surface.

At the present writing, no conclusions safely can be drawn if they depend very delicately on seismological assignments of hypocentral depths. Observations during the last few years have led to significant revision of interpretation for recorded seismic waves at short epicentral distances. This revision affects epicenters and depths to some extent, within the ranges mentioned above. Investigation is still in progress, and the course it takes will be materially affected by the unusually accurate and copious data obtained for the Kern County earthquakes of 1952.

Figure 4 shows epicenters determined for the larger shocks of the Kern County series. Those of magnitude 5 and over are indicated by shaded circles; there are 22 of these, and the listing is complete. Those of magnitude 4-5 are indicated by smaller solid spots, which include all epicenters whose locations had been worked out by the end of 1952. Some repetitions in location are not indicated separately. In addition, many more shocks were recorded. About 50 of them, for example, are estimated to have taken place within the first 3 hours on July 21, and locations for these are difficult, if not impossible to work out because of overlapping recordings. The much more numerous shocks of smaller magnitude are largely uninvestigated.

The location of the aftershock epicenters shows a significant progression in time. Aftershocks are known to have occurred along the entire active segment of the White Wolf fault, from the principal epicenter to a point near Caliente, for the first 36 hours; but all these aftershock epicenters lie southeast of the surface trace of this fault, and thus are consistent and compatible with a dip in that direction. After 36 hours, shocks began to occur northwest of the surface trace. On July 29, a series of shocks began with epicenters distributed along a line extending roughly northeastward from Bakersfield, and approximately parallel to the trace of the White Wolf fault. This series included a shock on August 22, which, though of magnitude no greater than about 5.6, was so close to Bakersfield that it caused more damage there than the principal earthquake of July 21. The alignment of these epicenters crosses folds and other structures exposed at the surface, which in that area trend more nearly northwest. This result recalls the relation of the Manix fault to the epicenters of the Manix series of shocks, and suggests a deep, active structure that possibly may be related to the canyon of the Kern River in that vicinity.

These results probably do not represent any unusual complexity. Our information on this occasion is exceptionally full, and is adequate to establish phenomena that probably are characteristic of most major events of the kind.

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San Francisco | Bulletin 170 | September 1954

GEOLOGY OF SOUTHERN CALIFORNIA

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CHAPTER X

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